Exploring Attention in VR: Effects of Visual and Auditory Modalities

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Abstract. Attention requires the ability to stay concentrated and alert to stimuli over prolonged periods of time. Virtual reality (VR) can be used in various training situations where attention plays a major role (e.g. system operators). Here, we investigate the effects of visual and auditory stimuli on attention performance in a VR aquarium (Nesplora Aquarium). Participants pay attention to the main fish tank and respond by pressing a button. The stimuli are different species of fish that are delivered either via visual or auditory channels. Thirty-seven participants completed the VR test and paper questionnaires. We found that attention is influenced differently by sensory modalities. Attention performance measured by the reaction time to correct targets and the number of errors of omission were better in the visual condition, while the number of errors of commission were lower in the auditory condition. The human factors' role in attention tasks is also discussed.

Keywords: Virtual reality · Visual and auditory attention · Sensory modality · Human factors

1 Introduction

Sustained attention or vigilance is a cognitive process important to human computer interaction (HCI) activities [1]. It requires the ability to maintain concentration and be alert to stimuli over prolonged periods of time. Failure to detect critical stimuli, to respond and take action in due time can have severe consequences in work environments that require sustained attention [2]. The effects of visual and auditory sensory modalities on sustained attention suggest that people respond faster to auditory stimuli when performing simultaneously a visual task [3, 4]. Effects of visual and auditory modalities on attention performance have not previously been investigated in a virtual reality (VR) setting which is considered to be more realistic and ecological and can predict better real-life performance [5].

Questions concerning how visual and sensory modalities influence attention are of high importance in the HCI field where the multisensory environment is complex. With VR technology being able to deliver realistic experiences, we can now test in a safe and ecological environment how sensory modalities impact attention performance. Results are important for designers of VR training platforms, so that they can develop VR environments that can accommodate multiple sensory channels and how this can improve performance and reduce distractibility and errors. Beside attention, mental workload and situation awareness are also important in work environments with monitoring tasks [2, 6]. Vigilance tasks pose an increased mental workload [1, 7] and attention increases situation awareness [8, 9]. Less is known about how people experience workload and situation awareness in visual and auditory attention tasks in VR.

1.2 Goals and Objectives

The present study is part of a larger collaborative project between one higher education institution and one industry partner from the EU. The project and subsequent studies aim to establish the normative and clinical validity [10] and usability [11] of the Nesplora Aquarium.

To date, no detailed examination of the pattern of change in reaction time and numbers of errors for visual and auditory modalities has been conducted in an immersive VR. Therefore, the major objective of this study was to compare in an immersive VR differences between visual and auditory stimuli on sustained attention. Based on studies conducted in other non-VR settings, we expect that attention will be better in the auditory condition compared to the visual condition. The second objective was to identify which sensory modality (e.g., visual and auditory) associated with increased workload and situation awareness. Because presence in VR and simulator sickness are important to VR research, we also investigated whether they might have an impact on visual and auditory attention. We anticipated that human factors (e.g., mental workload and system situation awareness), simulator sickness, presence in VR would correlate with visual and auditory attention performance in VR.

2 Method

2.1 Participants

Thirty-seven healthy participants aged between 23 and 55 years (M = 32.32, SD = 7.86), took part in the study. They were recruited via department mailing lists and word-of-mouth. Fifty one percent were females (N = 19) with a mean education years of 18 (SD = 3.13). Twenty participants (54%) reported previous VR experience and 28 were employed (76%). Exclusion criteria included (a) a clinical diagnostic of neurological and psychiatric conditions, (b) a moderate to major visual and hearing impairment, and (c) age under 18 years old.

2.2 VR System

The VR system used is Nesplora Aquarium [10] developed to measure attention in adults over 18 years. Attention performance is measured with the continuous performance test paradigm (CPT) embedded in the VR using a dual-task paradigm. Nesplora Aquarium is the first VR-based test to measure attention of adults and consists of vigilance CPTs (AX-types) administered in a virtual aquarium (see Figure 1). The VR system uses a Samsung Galaxy S7 smartphone, paired with Samsung Gear VR headset. The test is monitored by the experimenter, using a laptop computer (ASUS ROG, Intel i7 processor, 8 Gb RAM, GeForce GTX 960M videocard). Both the laptop computer and the VR headset are connected using a local wireless connection. During the test, the participant is virtually positioned in the main room of a VR aquarium. During the task, the participant has to pay attention to the main fish tank and has to respond to the stimuli. The stimuli were: a) images of different species of fish (e.g. clown fish) that were passing at high speed in the fish tank (visual condition) and b) names of fish heard in the speakers (auditory condition) (Figure 1).

2.3 Measures

Nesplora Aquarium outcomes were used as measures of sustained attention, more specifically: reaction time to correct responses in milliseconds, total number of missed targets (omission errors) and total number of incorrect targets (commission errors) (raw data). Omissions are linked to inattention and commissions to impulsivity [12]. Increased number of commission errors and omission errors and faster reaction times to correct answers reflect poor attention performance.

Raw NASA Task Load Index, Nasa-TLX [13] was used for subjective workload. Self-report situation awareness was measured using the Situation Awareness Rating Technique, SART [14]. To measure the subjective level of presence in VR we used the Presence Questionnaire version 2, PQ [15]. The level of simulator sickness was measured using the Simulator Sickness Questionnaire, SSQ [15].

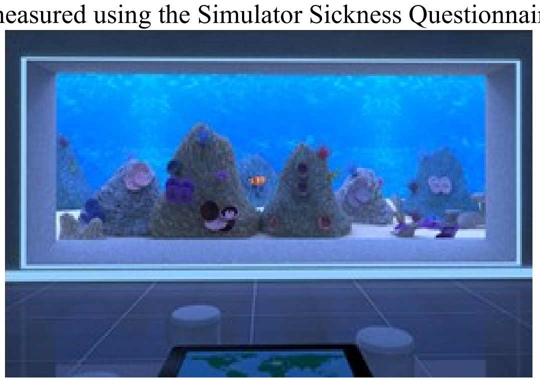

Fig 1. Screenshot of the Nesplora Aquarium VE with visual stimuli.

2.4 Procedure

The study was approved by the University Research Ethics committee (REF 6667/25.04.2018; PREC 18-305). After the participants read the information sheet and before the start of the study we obtained written consent. The screening and demographic questionnaire was completed at the beginning of the study. Participants not matching the inclusion criteria did not take part in the study. Participants first completed the Nesplora Aquarium test. The task lasted for approximately 18 minutes. At the end of the VR task, they had to fill in the questionnaires and measures: post-test SSQ, NASA-TLX, SART, and PQ questionnaires.

3 Results

3.1 Sensory Modality Effects on Attention in VR

For our first objective that aimed to test effects of auditory and visual stimuli on sustained attention, we have used a within subject design as the CPT used a dual-task paradigm. Cohen's *d* was calculated as a measure of effect size for the comparison between the two conditions [16]. Results from a paired-sample *t* test revealed significant differences for all attention outcomes: reaction time to correct targets, errors of commission and omission. Contrary to our prediction, reaction time to correct targets was slower for the auditory condition (M = 1037.99; SD = 310.94) compared with visual condition (M = 779.67; SD = 93.55), $t(36) = -4.61$, $p < .001$ (see Figure 2a) with a medium to large effect size, Cohen's $d = 0.75$.

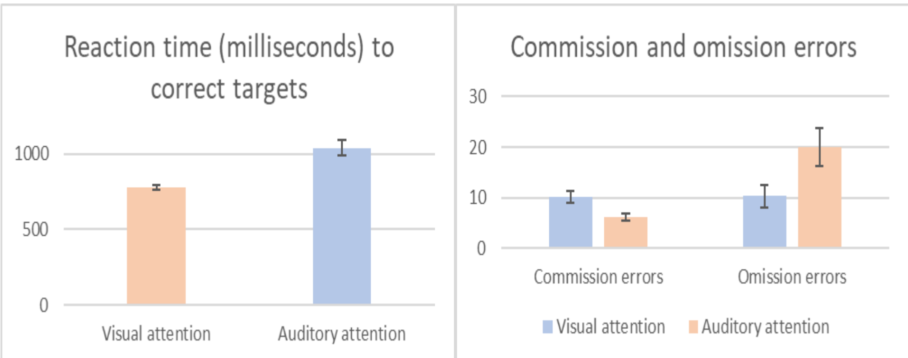

Fig 2. (a) Reaction time for visual and auditory conditions; (b) Commission and omission errors for visual and auditory condition. Error bars are standard errors.

As we predicted, the number of commission errors was higher for the visual condition (M = 10.21; SD = 7.28) than the auditory condition (M = 6.27; SD = 4.22), $t(36)$ = 3.63, $p < .01$ showing a moderate effect, Cohen's $d = 0.59$. Contrary to our prediction, errors of omission were higher in the auditory condition (M = 19.94; SD = 22.71) versus the visual condition (M = 10.32; SD = 13.23), $t(36) = -3.31$, $p < .01$ with a medium effect, Cohen's $d = 0.54$ (see Figure 2b).

For our second objective, we predicted that human factors (e.g., mental workload and system situation awareness), simulator sickness, presence in VR would correlate with visual and auditory attention performance in VR**.** We've used a cross-sectional design and Pearson *r* parametric correlations were conducted**.** We also employed Pearson's r correlations as a measure of effect size [16].

3.2 Visual Attention

Results indicate that mental workload was positively and moderately associated with reaction time on visual stimuli on correct responses, $r(35) = .31$, $p < .05$ and negatively on commission errors on visual stimuli, $r(35) = -.37$, $p < .05$ No association was identified for omission errors on visual stimuli, $r(35) = -.05$, $p > .05$. There was a weak and negative association between situation awareness and reaction time on visual stimuli, $r(35) = -.29$, $p < .05$. We obtained a moderate and negative association between situation awareness and the total number of omission errors on visual targets, $r(35) = -.42$, $p < .01$, but not for visual commission errors, $r(35) = -.07$, $p > .05$.

Post-test reported simulator sickness was correlated moderately and positively with reaction time on correct responses to visual stimuli, $r(35) = .39$, $p < .01$, negatively with visual commission errors, $r(35) = -.28$, $p < .05$, and positively with the total number of visual omission errors, $r(35) = .36$, $p < .05$. Presence in VR was not associated with visual attention performance outcomes (reaction time, $r(35) = .09$, $p > .05$; omission errors, $r(35) = -.00$, $p > .05$; commission errors, $r(35) = .08$, $p > .05$).

3.3 Auditory Attention

For auditory attention performance results revealed that none of the auditory attention outcomes correlated with mental workload (reaction time, $r(35) = .25$, $p > .05$; omission errors, $r(35) = -.15$, $p > .05$; commission errors, $r(35) = -.04$, $p > .05$). Similarly, nonsignificant results were obtained for the correlation between situation awareness and reaction time to auditory stimuli, $r(35) = .02$, $p > .05$, auditory omission errors, $r(35) = -.25$, $p > .05$ and auditory commission errors, $r(35) = -.25$, $p > .05$.

Post-test reported simulator sickness was negatively correlated with reaction time on correct responses to auditory stimuli, $r(35) = -.27$, $p < .05$ with low effect sizes. Simulator sickness correlated moderately and positively with auditory omission errors, $r(35) = .46$, $p < .05$. Nonsignificant correlations were obtained for auditory commission errors, $r(35) = -.04$, $p < .05$. Presence in VR was not associated with auditory attention performance outcomes (reaction time, $r(35) = .04$, $p > .05$; omission errors, $r(35) = -.00$, $p > .05$; commission errors, $r(35) = .01$, $p > .05$).

4 Discussion and Implications

A number of implications of the current study findings are important for future design, development and testing of VR systems. First, in an immersive VE reaction time to correct targets is better for visual stimuli. People can become more impulsive and commit more unwanted errors in the visual condition, but they become less vigilant and fail to respond to the correct targets in the auditory condition. We can conclude that visual stimuli in VR may increase impulsivity, while auditory stimuli increase inattention. Depending on the aim of the VR application, a careful selection of the visual or auditory channels might improve performance and attention. An overwhelming and complex task might actually reduce not only performance but disengage with the task when the cues are delivered via the visual modality.

Auditory tasks in VR slow down reaction time, so it is best to rely on visual cues for timed tasks. For tasks that require a high amount of monitoring over long periods but where an immediate response is required for critical situations, it is preferred to rely on the visual channel. On the opposite, for tasks that require monitoring of the stimuli and frequent interaction and responses to relevant information, auditory stimuli are recommended. VEs that support increased situation awareness will have a positively impact on reaction time and reduce impulsivity on visual tasks.

Despite the fact that presence is considered an important variable in VR research, it might be the case that for attention tasks in VR the sense of being in the VE and the quality of the immersion are not that important as in the field of memory and learning or in treating phobias. Our results also highlight concerns about the negative impact of simulator sickness on visual and auditory outcomes especially for omission errors. Increased simulator sickness might cause more inattention reflected in the number of missed correct targets. When designing and developing VEs for various training situations in which attention and monitoring of visual and auditory stimuli are at stake, researchers and developers should also consider the effects of increased simulator sickness on performance and try to reduce factors that are known to cause increased simulator sickness symptoms. For VEs that require tasks with fast detection time then the stimuli should be presented via the auditory channel, as the reaction time is faster in case of simulator sickness and it is less affected by it. Visual targets should not be delivered when suspicions of simulator sickness as this slows down the reaction time.

When designing VEs for training situations where attention plays a major role it is important to take into account the effects of sensory modalities as they influence attention performance. We conclude that the visual sensory modality increases impulsivity and the number of unwanted errors while the auditory modality increases inattention and the number of non-responses to correct targets and slows down the reaction time. We argue that VR systems that are used for training of various man machine interactions should account for sensory modalities depending on which component of sustained attention they are targeting to assess and train.

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